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SOLVING CHEMICAL PUZZLES: DETECTIVE MYSTERY AS A CONTEXT FOR TEAM-BASED LEARNING AND KNOWLEDGE INQUIRY

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Abstract

Engaging students in the process of learning chemistry is a significant challenge, prompting the growing use of active learning methods such as Detective Mystery. This study describes the application of this method in secondary school chemistry education, emphasizing its potential to develop analytical skills, collaboration, and logical thinking. The study presents two new chemistry-based Detective Mysteries designed by students of the Faculty of Chemistry at Jagiellonian University as part of their pre-service teacher training. The method's application was analyzed through observations, worksheets, and participant discussions.
The research demonstrated that the method effectively engages students in learning, enhances their understanding of chemistry concepts, and fosters the development of social skills. The introduction of roles such as leader and secretary, along with worksheets, improved task organization and ensured equal participation. However, challenges were noted, including overcoming introversion, managing emotions, and coping with information overload.
The presented puzzle scenarios differed in their scope of knowledge and approach, highlighting the flexibility of this method in adapting to various educational objectives. The conclusions underscore the need for adequate teacher preparation for implementing this method and reflection on its educational potential. This work serves as a valuable inspiration for chemistry teachers seeking to adopt innovative teaching approaches in schools.
Keywords: *detective mystery, active learning methods, chemistry education, microteaching, pre-service chemistry teacher training*

Introduction

Authentic student engagement in the process of learning and classroom activities remains a challenge for chemistry teachers worldwide. Many proposed solutions involve incorporating relevant contexts, allowing students to make decisions and demonstrate creativity, creating a safe environment that accepts misconceptions as the starting points for discussions, encouraging teamwork, fostering inquiry and problem-solving, integrating hands-on activities, and incorporating simulations. These strategies are frequently discussed in STEM education research (PCK).

In Poland, teachers have access to a publication titled *"Ja i mój uczeń pracujemy aktywnie"* (*My Student and I Work Actively*) by Brudnik, Moszyńska and Owczarska (2000), published at the beginning of the 21st century. This resource still serves as a repository of descriptions for methods and techniques that promote active learning. Among the 150 methods described, the "criminal puzzle/Detective Mystery" method is included. However, the majority of the active learning methods presented in the publication, including the previously mentioned one, focus on humanities, social sciences, and homeroom/personal development lessons or outreach activities, with limited applications in STEM education.

Detective Mystery: Characteristics of the Method

The "Detective Mystery" is an active learning method that engages students in solving a fictional criminal case, relying on logical reasoning, fact analysis, and collaboration. Students analyze evidence, formulate hypotheses, and draw conclusions based on available information. Lesson scenarios combining science content with elements of forensic investigation, which enhance the attractiveness of learning, have been published by various authors (e.g., Bader & Rothweil, 2009; Basso et al., 2018; Maciejowska, 2003; Muller, 2011).

Two key aspects of this method stand out:

1. Forensic Experiments: Using scientific experiments to solve problems, such as fingerprint analysis, ink chromatography, blood sample analysis, or the examination of mixtures and alloys.
2. Integration of Criminal Context: Introducing elements of crime-solving into non-experimental lessons, often inspired by famous works of fiction, such as those by Agatha Christie.

Forensic chemistry themes have also been applied in educational tools like chemistry-based escape rooms (Ferreiro-González et al., 2019) and board games focused on chemical trace analysis (Odrowąż et al., 2022). While Detective Mysteries are often used to popularize STEM disciplines through outreach and informal education, their use in regular classroom settings—especially in Polish educational journals—is not well-documented.

The Detective Mystery method, described by Brudnik et al., (2000, p. 276-279), follows a specific structure. It is a teaching and learning technique where information is deliberately divided among group members. Each participant receives fragments of knowledge, which may be critical, less important, irrelevant, or even incorrect, presented on slips of paper containing investigative details. To solve the problem, participants must communicate, exchange information, and piece the clues together like a puzzle.

The teacher provides classic guiding questions on the board, such as:

- Who (committed the crime)?
- When (did it happen)?
- Where (did it occur)?
- How (what was the method, motive, or tool used)?

The teacher refrains from aiding or guiding students during the activity. This method is an example of an Information Gap Task, commonly used in language teaching and learning (Richards & Schmidt, 2009) and increasingly applied in university-level STEM education (Summerfield, Overton & Belt, 2002).

Objectives of the Detective Mystery method are quite complex and include: developing information management skills, fostering collaboration and communication, promoting active learning, enhancing logical thinking. Cooperation goes beyond simply arranging students into groups. Some essential elements must be embedded in the learning environment e.g. students must feel that their success is linked to the success of others, each member of the group has personal responsibility for contributing to the task, group members encourage and support each other, reflect on group activities to evaluate their efficiency and improve future cooperation is reinforced (Johnson & Johnson, 2018). The teacher informs students that solving the puzzle will be a shared success, while failure to solve it will be a shared failure. This reinforces the understanding that there are situations in life where only teamwork can lead to success, and acting alone is destined to fail.

To enhance the exercise, the teacher or the group can assign an observer from among the students. The observer closely monitors the group's activities and records observations in an observation sheet. The observer answers questions such as:

- How did the group organize its work?
- How did it approach the task?
- Were specific roles assigned or adopted naturally?
- Did anyone dominate the discussion?
- Was there someone who coordinated the conversation, kept track of time, took notes, or ensured that everyone participated?
- Who contributed the most ideas?
- Was everyone equally active?

These observations help to assess how the group's dynamics influenced the overall progress of the task. Including an observer adds an extra layer to the method, adapting it into a version of the "fishbowl" technique, in which a small group performs a task or engages in problem-solving while the rest of the class observes. During the activity, the teacher can also observe students' collaboration, including their ability to work with both friends and randomly assigned team members. The teacher might note how students handle conflicts, such as choosing key clues or dismissing irrelevant information, and how they piece together facts to form logical sequences. Such observations can provide the teacher with deeper insights into each student's strengths and areas needing support, helping to adapt teaching strategies to the group's needs. However, one challenge of this method is that students may struggle to organize group work independently (Brudnik et al., 2000).

The study aimed to evaluate the advantages and limitations of the Detective Mystery method in teaching and learning secondary school chemistry, aligned with the national curriculum. This method was chosen for its potential to engage students and develop problem-solving skills using scientific knowledge, as well as due to the scarcity of research on its effectiveness in Polish educational contexts. An additional goal was to encourage reflection on the actions of students—future chemistry teachers—whether in the role of leading an exercise as part of microteaching or participating in it.

The study also aimed to provide new detailed examples of chemistry-based Detective Mysteries for teachers, enabling them to implement the method in their classrooms.

Research Methodology

A case study approach was adopted to explore examples of the Detective Mystery method in real-life educational contexts simulated by microteaching activity. This holistic method included observations, document analysis, and surveys to examine relationships, patterns, and outcomes. Case study methodology allows the exploration of unique phenomena and the formulation of practical recommendations (Budzanowska-Drzewiecka, 2022; Yin, 2018).

Sample, Instrument and Procedures

Students from the Jagiellonian University's Faculty of Chemistry pre-service chemistry teacher training, are introduced to various active learning methods during their coursework. As part of the *Didactics of Chemistry III* course in their fifth year of their study, students are required to adapt or develop a new teaching and learning method and test its applicability through a microteaching session with their peers.

During the 2024/2025 academic year, 18 students (12 women and 6 men) from the chemistry and medical chemistry study programs participated in the course. In the first phase, 15 students participated in solving a Detective Mystery. Students received no prior information beyond the standard guiding questions and worked all together as a single group. Their activities were observed by the academic instructor and three other students.

Based on observations, discussion and feedback from this first phase/stage, the method was refined by the students in preparation for the second phase. In this phase, two pairs of female students independently designed new Detective Mysteries, incorporating modifications to address challenges identified previously. During the final course session, these methods were tested with the participation of the entire group.

The analysis drew on several sources of data:

• Observations by the student facilitators (authors of the Detective Mysteries) and designated group observers.

• Student worksheets evaluating the preparation and execution of the exercise (each participant completed an individual form).

• A group discussion was conducted after the exercises to gather reflections and insights.

• Observation by the academic instructor.

Detective Mystery Scenarios

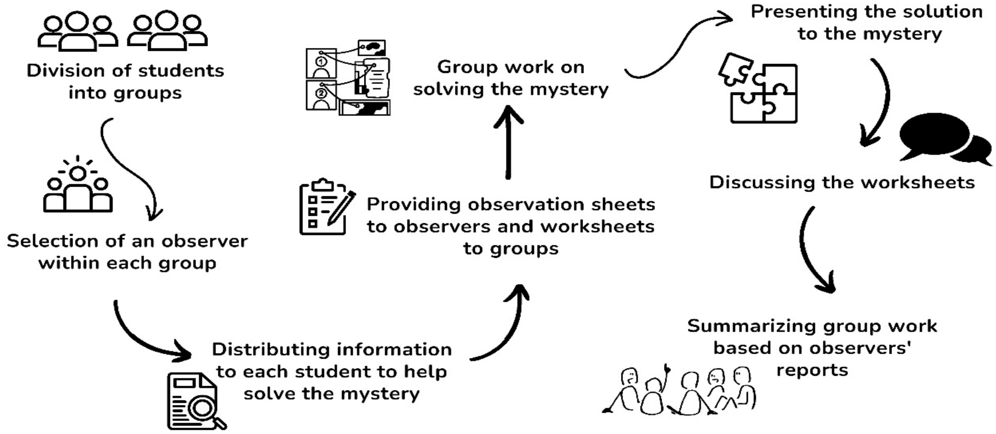
The Detective Mystery scenarios were developed based on the principles described in the literature (Brudnik et al., 2000). They were designed to align with the educational goals outlined in the Polish National Curriculum for the advanced chemistry education track in secondary schools (Ministry of National Education, 2018). Below, the process, content, and modifications introduced to the scenarios are discussed in detail.

Scenario A: "The Mysterious Murder of Dr. Damian"

The lesson following Scenario A was conducted in several stages, as outlined schematically in Figure 1. Initially, the students were divided into two groups of eight, and each group selected one student to act as an observer. The observers were provided with observation sheets containing questions related to the group's collaboration. In this Detective Mystery, in addition to the observation sheets, worksheets were introduced to better structure the discussion process (compared to the first phase, where the puzzle was conducted by the instructor without such tools). All materials necessary for this exercise are presented in the subsequent sections of the article (Figures 1, 2, 3).

After completing the puzzle, each group presented its solution. Since only one solution was correct, the student facilitators revealed the correct answer and, together with the second student group, reviewed the responses to the tasks listed on the worksheet, which were intended to guide the participants toward the correct solution. Finally, based on the data recorded in the observation sheets and the impressions shared by the participants, a discussion was held regarding the effectiveness of group work.

Figure 1
Organization and course of classes according to scenario A (prepared by Katarzyna Tarasek)



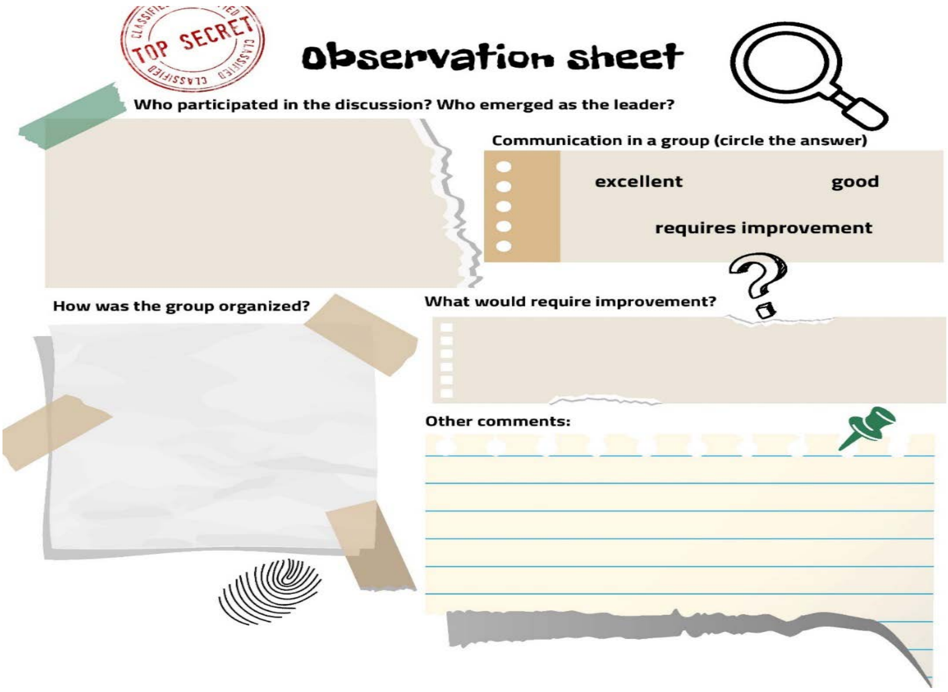
The developed Detective Mystery consisted of 28 pieces of information, the content of which is presented below.

1. *On Friday evening, a reunion of chemistry graduates after 10 years took place at the Cristal Hotel. At 1:30 AM on Saturday, Dr Damien's body was found by his wife, Anna, in their hotel room.* 2. *According to the coroner, Dr Damien was murdered between 11:30 PM and 12:30 AM, based on rigor mortis, livor mortis, and algor mortis. The cause of death was identified as a stab wound to the chest.* 3. *Commissioner Novak stated that the main suspects in the case are the wife, Anna, and two of Dr Damien's colleagues who attended the reunion the previous evening.* 4. *A suspicious powder was found at the crime scene.* 5. *It was determined that the substance found at the crime scene reacts with acids and bases but does not react with water.* 6. *Thaddeus works in a laboratory, handling compounds of a certain metal with the electronic configuration: [Ar] $4s^1$ $3d^5$.* 7. *Jack works for the company FERRO, where he produces a certain metal using a green powder via the aluminothermic method.* 8. *Jack's workplace involves producing a metal characterized by high hardness, a pale blue color, a high melting point, and a strong metallic luster.* 9. *Anna, Dr Damien's wife, works as a chemistry teacher. On the same day as the reunion, she performed a demonstration with her students, showcasing an experiment often referred to as the "chemical volcano."* 10. *Commissioner Novak learned from a chemist acquaintance, Marie Skłodowska, that the "chemical volcano" experiment involves the decomposition of ammonium dichromate (VI).* 11. *In Thaddeus's hotel room, several test tubes and a beaker containing a yellow solution were found. Additionally, a number of reagent containers were left on the table: sulfuric acid (VI), sodium hydroxide, and hydrogen peroxide.*

12. *Among the reagents in Thaddeus's room, an empty, unlabeled box was also found.*
13. *Jack arrived directly from work to the reunion.*
14. *Anna testified that during their studies, Jack failed to secure a spot in the doctoral program and resented Damien for easily getting in and taking his place, a fact also confirmed by Thaddeus.*
15. *Jack testified that at 1:00 AM, he saw Thaddeus and Anna kissing near the hotel bar.*
16. *Both Thaddeus and Jack are envious of Damien's academic success.*
17. *The bartender testified that Anna was at the bar from 11:00 PM to 1:00 AM.*
18. *No evidence matching the traces found at the crime scene was discovered in Jack's room.*
19. *Commissioner Novak learned that Anna and Damien had signed a prenuptial agreement before their marriage.*
20. *In Dr Damien's notebook, a note was found: "Meet with Jack – project."*
21. *Jack claims that he was meeting with a colleague at the bar from 10:30 PM to 1:30 AM that evening.*
22. *Jack had previously blackmailed Thaddeus during their studies.*
23. *The yellow solution found in Thaddeus's room turned orange upon adding sulfuric acid (VI) during identification tests.*
24. *A wet stain was found near the radiator in Thaddeus's room.*
25. *Thaddeus claims that he was with Anna from 11:00 PM to 1:00 AM at the bar, reminiscing about the old times.*
26. *Anna confirmed the testimonies of both Thaddeus and Jack.*
27. *The camera recorded Jack at the bar from 10:30 PM to 1:30 AM, and Thaddeus from 12:30 AM to 1:00 AM. Additionally, it captured Jack leaving the bar at 12:00 AM and returning at 12:15 AM.*
28. *Commissioner Novak, a symmetry enthusiast, noticed upon entering the hotel that the ice sculpture had six icicles on the right side and five on the left.*

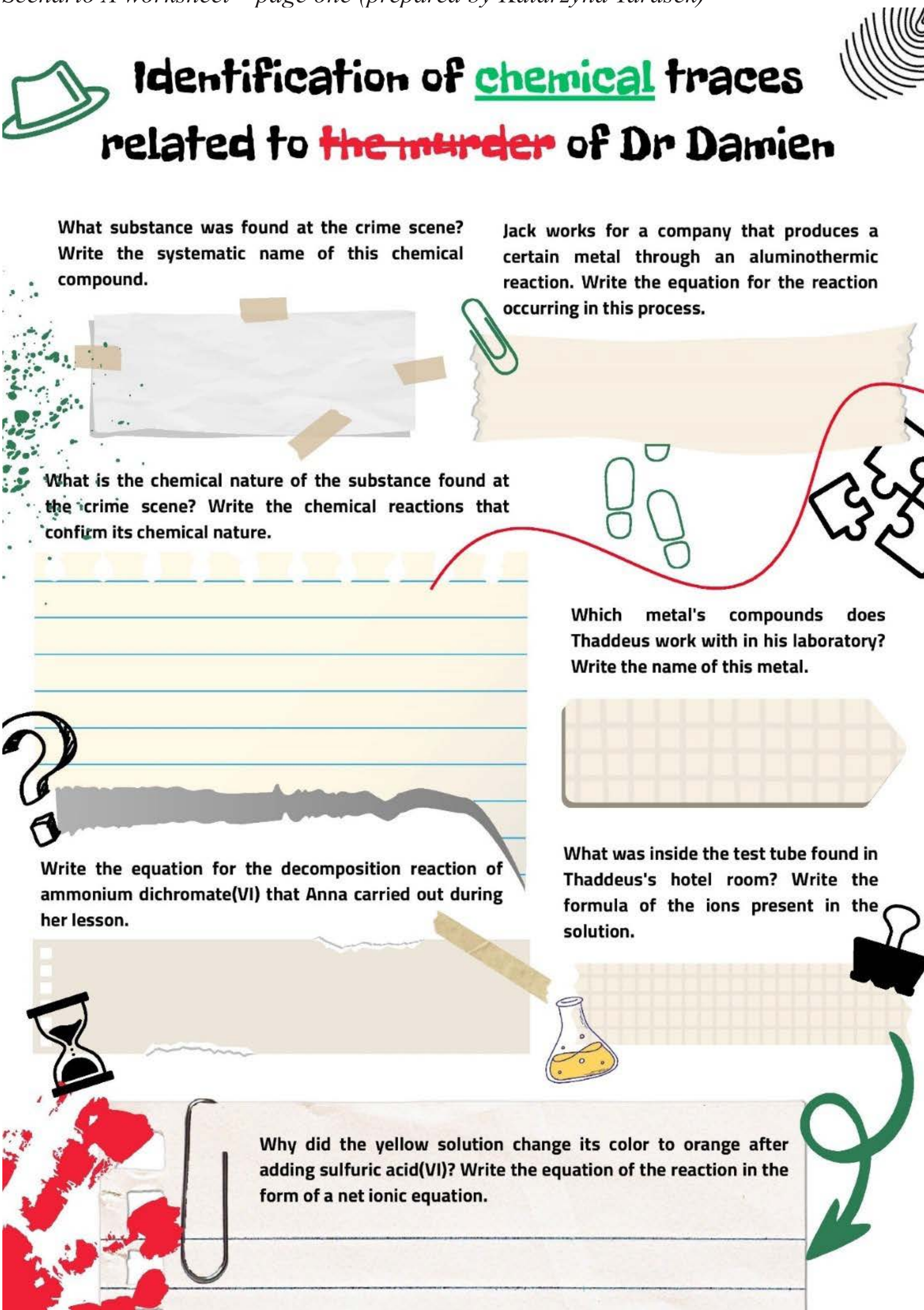
A group work observation sheet is presented in Figure 2. Its purpose was to facilitate discussion of the dynamics of group work, which discussion, together with appropriate reflection, is intended to improve cooperation in the future

Figure 2
Scenario A observation sheet (prepared by Katarzyna Tarasek)



The proposed worksheet for group work participants was intended to support students in systematically collecting information and formulating conclusions. The prepared set of questions is presented in Figures 3 and 4.

Figure 3
Scenario A worksheet – page one (prepared by Katarzyna Tarasek)



Identification of chemical traces related to ~~the murder~~ of Dr Damien

What substance was found at the crime scene? Write the systematic name of this chemical compound.

Jack works for a company that produces a certain metal through an aluminothermic reaction. Write the equation for the reaction occurring in this process.

What is the chemical nature of the substance found at the crime scene? Write the chemical reactions that confirm its chemical nature.

Which metal's compounds does Thaddeus work with in his laboratory? Write the name of this metal.

Write the equation for the decomposition reaction of ammonium dichromate(VI) that Anna carried out during her lesson.

What was inside the test tube found in Thaddeus's hotel room? Write the formula of the ions present in the solution.

Why did the yellow solution change its color to orange after adding sulfuric acid(VI)? Write the equation of the reaction in the form of a net ionic equation.

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Figure 4

Scenario A worksheet – page two (prepared by Katarzyna Tarasek)

The circumstantial evidence, proof, motives, and conclusions confirming or refuting the involvement of the suspects in the crime are presented in Table 1.

Table 1
Reasoning Process and Resulting Solution – Scenario A

Suspect	Circumstantial Evidence	Proof	Motive	Conclusion
Thaddeus	Wet stain near the radiator, sodium chromate(VI) solution, and an empty, unlabeled container.	Lack of alibi during the time window of the murder, evidence of erasing traces by melting an icicle and conducting chemical reactions to dispose of chromium(III) oxide.	Envy of Damien's successes, past blackmail by Jack, affair with Anna.	**YES**
Anna	Demonstration of the "chemical volcano" experiment – possible traces of Cr_2O_3 from the decomposition of ammonium dichromate(VI).	No evidence – alibi consistent with camera footage and witness testimonies.	No direct financial gain (prenuptial agreement), but possible motive to hide the affair.	**NO**
Jack	Came straight from work where he uses a green powder.	Cameras show a break between 12:00 AM and 12:15 AM, during which he could have left the bar to commit the crime, but no traces were found in his hotel room.	Envy of Damien's successes, past conflicts regarding the doctoral program.	**NO**

The solution to the murder of Dr Damien lies in answering the questions outlined in the worksheet. The information provided to the students as a whole should unequivocally identify Thaddeus as the perpetrator of the crime.

Thaddeus murdered Dr Damien using an icicle, which he quickly melted after the crime to erase evidence. He attempted to frame Jack by planting chromium (III) oxide, which Jack commonly handles in his work. However, the presence of a yellow solution, chemicals in Thaddeus's room, and his lack of an alibi confirm his involvement in the crime. Thaddeus's actions were motivated by jealousy of Damien's academic successes. Additionally, he sought revenge against Jack, who had blackmailed him in the past. Table 1 presents the circumstantial evidence, proof, and motives for all suspects, along with conclusions confirming or refuting their involvement in the crime.

Detective Mystery Scenario B – "The Mysterious Accident in the Laboratory"

In this case, the role of the observer was omitted, with the focus placed instead on selecting a leader and a secretary within each group. This adjustment aimed to streamline the organization of group work from the very beginning. As part of the puzzle, students

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received additional tasks from the teacher. These tasks enriched the game with more chemistry-related content while maintaining the appeal of the proposed method.

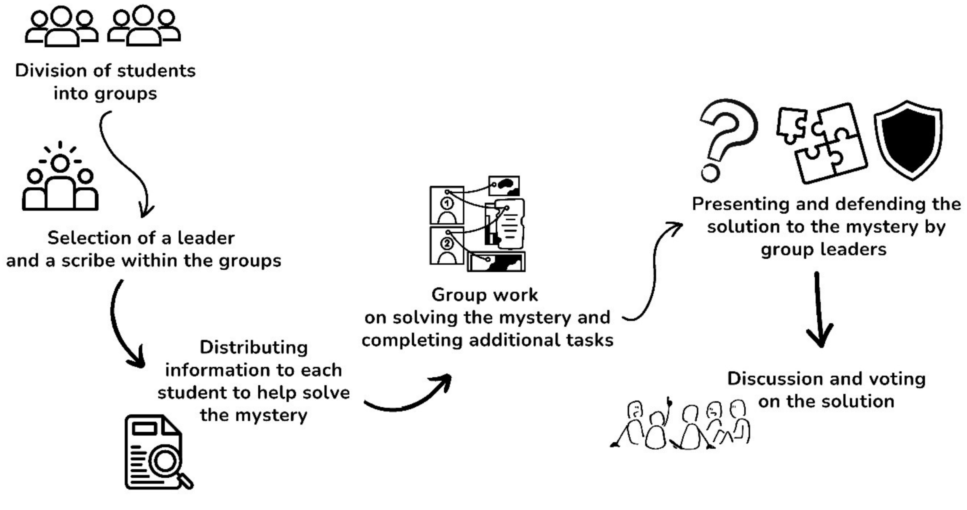
Another modification compared to the literature-based version conducted by the instructor was the inclusion of a comprehensive introduction provided by the student facilitators (authors of the Detective Mysteries). This introduction described the situation in detail, helping participants orient themselves in the task and reducing the overall duration of the exercise.

After completing the puzzle, the group leaders presented their solutions, justifying their conclusions by showcasing their responses to the additional tasks. Since the puzzle solutions differed between groups, the facilitators conducted a vote to determine the final version of the solution.

The stages of the lesson conducted according to this scenario, incorporating the modifications, are schematically presented in Figure 5. All materials necessary for this exercise are provided in the subsequent sections of the article.

Figure 5

Organization and course of classes according to scenario B (prepared by Katarzyna Tarasek)



Introduction to the Exercise

At 2:45 PM, an internal phone call was made within the department. A terrified Mr. Smith, a doctoral student working at the university, reported a gas leak in the laboratory where he was present. Together with his supervisor, Professor Novak, they were unable to leave and were on the verge of losing consciousness. After 15 minutes, rescuers, accompanied by firefighters, broke down the lab door and found the scientists unconscious. Unfortunately, despite resuscitation attempts, Professor Novak could not be saved.

Clues and Observations (the guidelines gathered during the investigation)

The professor's never-washed mug was found cleaned, though not thoroughly.
2. *Not all barium salts are water-soluble.*
3. *The released gas was odorless and heavier than air.*
4. *Professor Novak's latest publication contained results strikingly similar to those in Mr. Smith's unfinished doctoral thesis.*
5. *An autopsy revealed the presence of* Ba^{2+} *ions in Professor Novak's body.*
6. *The* Ba^{2+} *ions were evenly distributed across all tissues in the deceased.*
7. *Department technicians recorded a manual deactivation of the ventilation system at 2:40 PM.*
8. *Professor Novak followed a strict routine: coffee with lunch and a bathroom visit while the coffee cooled.*
9. *Despite sprinklers being activated during the rescue, a white substance on the floor did not dissolve.*
10. *A spilled liquid turned universal indicator paper red.*
11. *Investigators determined that the product obtained through thermal decomposition of the substance collected from the floor could cloud limewater.*
12. *Flame testing of the substance found at the scene produced a characteristic brick-red flame.*
13. *The barium carbonate packaging had a label inconsistent with the manufacturer's design.*
14. *No traces of barium ions were found on Mr. Smith's clothing or in his respiratory tract.*
15. *Mr. Smith's doctoral work focused on alkaline earth metals.*
16. *During the last seminar, Professor Novak publicly criticized Mr. Smith, saying he was far from becoming a valuable researcher.*
17. *The team's lunch break was scheduled from 1:30 to 2:00 PM.*
18. *A sachet with traces of a salt producible by a reaction with a binary acid was found in the social room trash.*
19. *In the department library, a book titled Foundations of Inorganic Chemistry was found open to page 827.*
20. *Mr. Kowalsky, an embittered long-time employee, was responsible for maintaining order among reagents.*
21. *Professor Novak influenced the committee's decision to hire Mr. Kowalsky as a technician rather than a researcher.*
22. *The lab door lock showed signs of tampering.*
23. *On the day of the incident, Mr. Kowalsky left work earlier than usual.*
24. *Witnesses confirmed that Mr. Smith spent the entire break in the social room.*
25. *Documents indicated that Professor Novak had previously disregarded safety procedures in the lab.*
26. *Analysts added sodium sulfate to the professor's mug and observed a white precipitate in the crevices. The collected precipitate colored a flame green.*
27. *Large amounts of white powder, partially covered in a colorless liquid, were found on the lab floor.*
28. *An empty container of barium carbonate was found near the scattered white powder.*

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Additional task: Four Reactions Producing the Substance Responsible for Professor Novak's Death

The circumstantial evidence, proof, motives, and conclusions confirming or refuting the involvement of the suspects in the crime are presented in Table 1.

Table 2

Reasoning Process and Resulting Solution – Scenario B

Suspect	*Clues*	*Proof*	*Motive*	*Conclusion*
Mr. Smith	*Ba^{2+} ions in the professor's mug; research overlap; professor's criticism.*	*No barium traces on Smith's clothing or respiratory tract; Smith stayed in the social room.*	*Research theft, public humiliation by the professor during a seminar.*	***YES***
Mr.	*Responsible for reagent organization; left work early.*	*No evidence; tampered labels on reagent containers.*	*Professor Novak's influence against hiring Kowalsky in a research position.*	***NO***
Accident	*Professor's disregard for safety protocols.*	*Large amounts of white powder and acid spill; tampered reagent labels.*	*Carelessness and protocol neglect by Professor Novak.*	***NO***

Solution

Mr. Smith's motive for murdering Professor Novak was research theft and sabotage of his academic career. The murder was executed through poisoning with water-soluble barium chloride. Less than a gram of the substance was added to the professor's coffee while he was in the restroom during lunch. The coffee was consumed during the break, and the mug was washed for the first time since its purchase to eliminate evidence.

Barium chloride poisoning acts quickly, causing nausea, dizziness, unconsciousness, muscle spasms, and ultimately respiratory paralysis. To stage the incident as an accident, Mr. Smith locked himself and the professor in the lab with a disabled ventilation system. As the professor displayed symptoms of poisoning, Smith called for help. During the rescue, Smith scattered a large amount of calcium carbonate and poured hydrochloric acid over it, releasing carbon dioxide, which could explain his feigned unconsciousness.

The barium carbonate used was mislabeled as calcium carbonate, and the lack of barium traces on Smith's clothing or body betrayed the substitution.

Observations and Results

Phase/Stage I: Whole Group Discussion

Observations and discussions following the completion of the exercise revealed that achieving equal participation among all members of a 15-person group was challenging. During the activity, several natural leaders emerged, which, given the limited time, complicated the group's workflow. The absence of a single designated leader hindered the coordination of decision-making, and the lack of an assigned note-taker at the outset made it difficult to analyze and resolve the problem effectively.

The group's activity fluctuated, with periods of focused work on a single thread or solution, phases of stagnation, and moments of parallel discussions and mini-debates

within smaller subgroups. The lack of a comprehensive introduction to the scenario by the instructor (apart from the standard questions typical for Detective Mysteries) slowed progress. Information about the scenario became widely understood only after one participant took the initiative to share their interpretation.

On the positive side, a significant portion of participants demonstrated high engagement in the discussion. The positive emotions associated with the activity contributed to the decision of two pairs of students to test this method during their microteaching exercises.

Phase/Stage II: Work in Two Subgroups with Modifications

Participant Activity

- Working in smaller teams, where the information was divided into parts and each participant's input was essential for achieving the objective, encouraged the active involvement of all members and fostered group integration. During the post-task discussion, participants expressed that this experience heightened their sense of responsibility for the shared outcome.
- In the smaller groups of Stage II, students who had remained silent in the larger group during Stage I were more likely to engage in discussion and exchange information on their own initiative.

Work Organization

- The introduction of a designated leader facilitated the orderly presentation of information and the formulation of solutions in most groups. Moderating the discussion reduced the likelihood of dominance by a few highly active participants, a phenomenon observed during Stage I. In one out of four cases, assigning the role of leader was less effective, as the individual chosen lacked natural leadership qualities and was relegated to merely presenting the group's results.
- Requiring the selection of a note-taker through task instructions enabled groups to better organize information and track emerging threads in every case.
- The use of worksheets improved the organization of tasks, made it easier to monitor progress, and ensured more equal participation among students.
- Providing a brief introduction to the scenario (as in Scenario B) and displaying it continuously on a screen allowed participants to start the task more quickly and return to the main point as needed, enabling faster completion of the exercise.
- Students expressed satisfaction with the simplifications introduced in Stage II, such as the initial scenario description and the mandatory selection of a leader and secretary. In their opinion, these changes brought greater order to the problem-solving process and allowed for quicker resolution of the task.
- Despite the modifications introduced in Stage II, certain issues, such as difficulties in overcoming introversion or unequal participation, persisted, though to a lesser extent.

Emotions

- It was observed that the method posed challenges for shy students, those feeling out of place in a new team, or those who were reluctant to speak in a group for other reasons. This highlighted the importance of the leader's role in ensuring that everyone had the opportunity to contribute.

- Adopting the role of detectives deeply engaged students emotionally. This was evident not only in their high level of activity but also in moments of frustration and even conflict arising from information overload or incorrect leads. For instance, disputes occasionally emerged over responsibility for overlooked clues.
- Some observers noted that not all emotions were positive, and these influenced the group's dynamics. For example, rivalry between groups occasionally led to tensions, such as accusations of insufficient effort by certain members.

Knowledge and Skills Development

- Students assigned to the additional roles introduced in Stage II (leader, note-taker, and observer) had the opportunity to identify their strengths and challenges associated with these responsibilities, which they shared during the final discussion.
- Observers provided valuable feedback on group dynamics and individual behaviors, which participants considered instrumental in reflecting on group processes and improving teamwork skills.
- The exercise reinforced students' knowledge of specific chemistry topics and allowed them to apply this knowledge practically to problem-solving.
- Justifying chemistry-based proposals during discussions helped peers identify and address misconceptions, contributing to a deeper understanding of the material.

The facilitators observed that participants eagerly engaged in the problem-solving process. The context and the unconventional thinking required by the tasks captured their interest and provided a sense of satisfaction. Working in smaller teams particularly increased the involvement of individuals who had previously remained in the shadows of their more vocal peers.

Reducing the number of participants per group mitigated the dominance of more assertive individuals, allowing responsibilities to be distributed more evenly and fostering a sense of collaboration and shared accountability. However, a notable challenge was the difficulty students faced in managing information overload and misleading clues, which led to conflicts in some groups. Students often shifted blame for mistakes, such as overlooking key clues or failing to pass them along, which caused frustration. Nonetheless, these situations also served as valuable learning opportunities: participants practiced data selection, responding to errors, and navigating conflicts constructively.

Conclusions and Implications

The Detective Mystery method effectively engages participants in revisiting chemical concepts (Retrieval-Based Learning) and in analyzing and establishing connections between known facts. It also helps develop the ability to identify cause-and-effect relationships. However, the method presents challenges, such as dealing with excessive or inconsistent information and "self-censorship," where participants disregard information they deem irrelevant.

Providing detailed instructions, preassigned roles, or worksheets improves task organization and promotes equal participation within groups. However, this structure can limit opportunities for learning from mistakes and deeper reflection on group work processes. This type of support is preferred by most pre-service teachers, who may feel

more comfortable with clear guidance and direction, either due to their perspective as university students or their imagined roles as secondary school students.

To enable the teacher to effectively understand students' work styles and aptitudes, it is crucial to allow them to take on different roles rather than assigning the same function throughout. This can be achieved through random role assignment, teacher designation, or voluntary selection, but it must always be monitored by the teacher. Only such an approach helps students gain better self-awareness and understand their capabilities in teamwork settings.

The method generates intense emotions, which can lead to tensions within groups, but it also provides opportunities to learn conflict management, data selection, and error response, if an appropriately large amount of time is allocated to it. Conflicts arising from incorrect decisions or frustrations highlight the need for better process management, including clearly defined rules and steps established by the group.

Given these challenges, the role of the leader or discussion coordinator is essential. Observations indicated that fulfilling this role effectively cannot rely solely on the intuition of the person assigned to it. Assigning this task without proper preparation is inadvisable. Leadership and coordination skills require deliberate cultivation, which teachers should consider integrating into their instructional strategies.

Some emotionally charged university students, whose work in two groups simultaneously could not be fully monitored by the facilitators, occasionally used sarcasm and irony in their small-group discussions. While such expressions are often seen as a sign of intelligence in STEM university environments, sarcasm and irony in school pedagogy are more controversial and should be used with great caution, if at all. Pre-service teachers should be made aware of this distinction.

The tested scenarios varied in format, approach to the puzzle, and the scope of knowledge required, which stemmed from different sections of the Polish chemistry curriculum. This diversity demonstrates that while the method has a defined structure, it allows for significant interpretation by its creators. Tailoring the method to specific educational goals and student needs enables creative teaching that combines theory with practice in an engaging and inspiring way.

The two new chemistry-based Detective Mysteries developed by students from the Faculty of Chemistry at Jagiellonian University, presented in this study, can serve as a resource for readers of *GU/NSE* either directly or after adaptation.

Declaration of Interest

The authors declare no competing interest.

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